Appendix D
Fast Flux Test Facility Operations

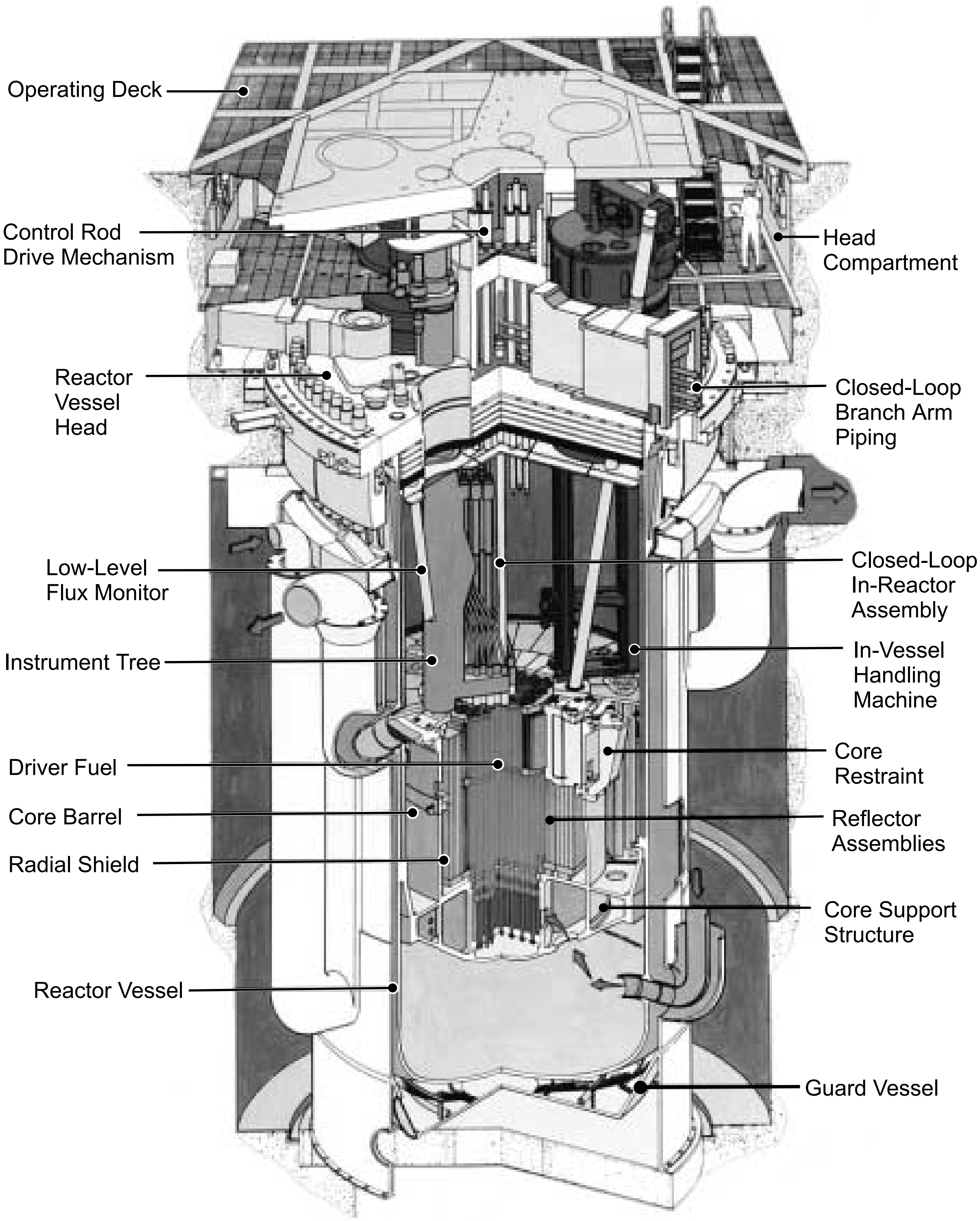
D.1 FAST FLUX TEST FACILITY DESCRIPTION

The Fast Flux Test Facility (FFTF) is an advanced liquid-metal-cooled research reactor located in the 400 Area of the Hanford Site. This appendix provides a description of FFTF operations that is based on the *Fast Flux Test Facility Data Request in Response to Data Call from Nuclear Infrastructure Programmatic Environmental Impact Statement* (Nielsen 1999). The reactor (**Figure D–1**) is located in a shielded cell in the center of the containment building. Heat is removed from the reactor by liquid sodium circulated under low pressure through three separate closed primary piping systems, referred to as loops, which include pumps, piping, and intermediate heat exchangers. These loops are located within inerted cells in containment. **Figure D–2** is a cutaway view of the containment building showing the location of the reactor, primary pumps, and intermediate heat exchangers. Three secondary sodium loops transport the reactor heat from the intermediate heat exchangers to the air-cooled tubes of the dump heat exchangers for dissipation to the atmosphere (FFTF does not generate electricity). **Figure D–3** depicts one of the three cooling loops.

FFTF is a versatile fast flux reactor capable of producing plutonium-238 and a variety of medical and industrial isotopes, as well as supporting materials testing and nuclear research and development activities. Due to the reactor size, the number of available test locations, and the instrumentation capabilities for monitoring individual irradiation and test locations in the core, a wide variety of irradiations and tests can be carried out concurrently.

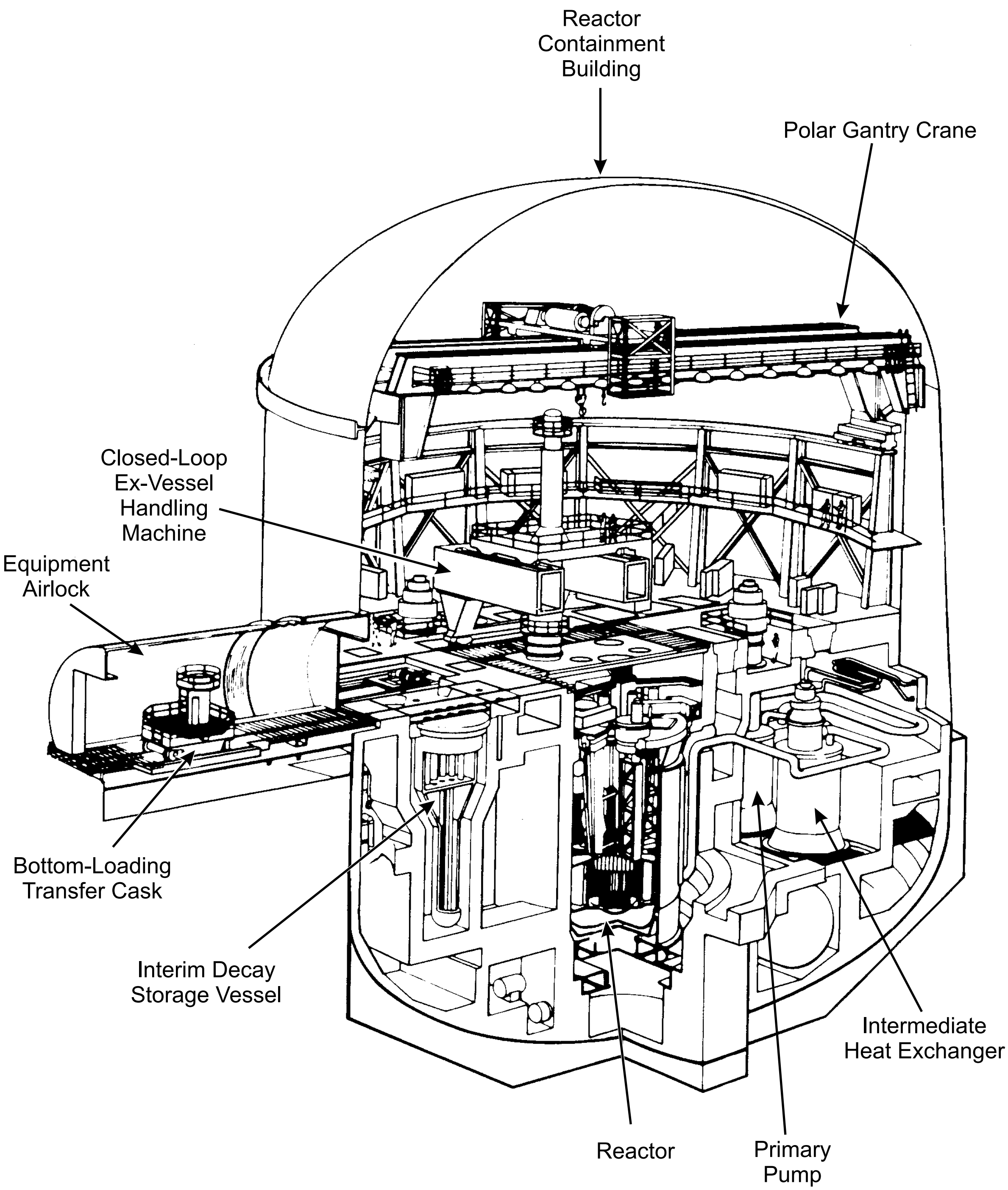
The term "fast flux" is indicative of the high energy (speed) of the neutrons within the reactor core. The total flux density of FFTF (fast plus thermal neutrons) is significantly higher than in a light water reactor. A supply of fast or high-energy neutrons allows FFTF to test a variety of materials and carry out research in an environment where fast neutrons are needed. For producing many isotopes, a thermal neutron environment may be more desirable. In this case, FFTF can slow down, or thermalize, fast neutrons by placing appropriate materials around the irradiation targets. **Figure D–4** shows a possible multitest core configuration for the various missions under consideration. These various reactor locations are discussed in the following paragraphs.

There are eight locations available in the reactor that are called open test assembly positions. These eight locations are distinct from the rest of the reactor in that they allow direct-contact instrumentation for remote monitoring during reactor operations. They are called "open" because they are directly cooled and exposed to the sodium environment within the reactor, as are most of the in-vessel components. What makes these locations distinct are the instrument stalks attached to them that communicate with and extend above the reactor head for routing of various instrumentation packages (**Figure D–5**). They also are positioned so that they allow for inner (core row 2), middle (row 4), and outer (row 6) reactor fluence environments. As many as eight Rapid Radioisotope Retrieval systems could be installed in these positions for the production of short-lived isotopes. However, it is expected that initially only one of these rapid retrieval systems would be installed in open test assembly positions in the reactor core.



Source: Nielsen 1999.

Figure D–1 Cutaway View of the FFTF Reactor Vessel



Source: Nielsen 1999.

Figure D–2 Cutaway View of the FFTF Containment Building

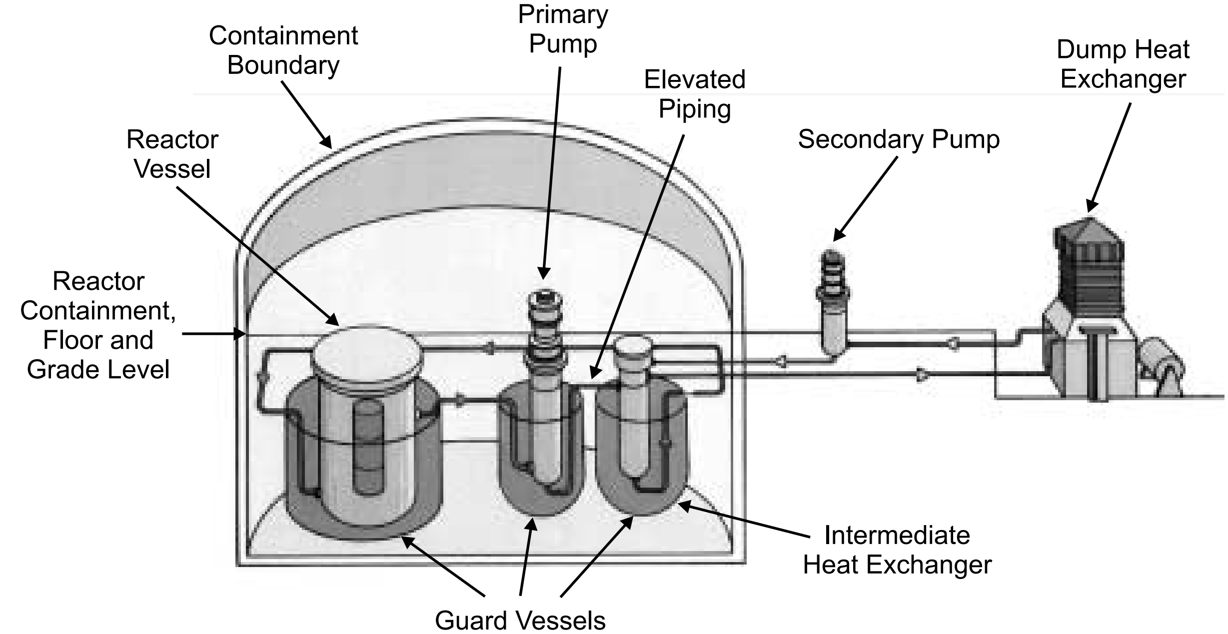
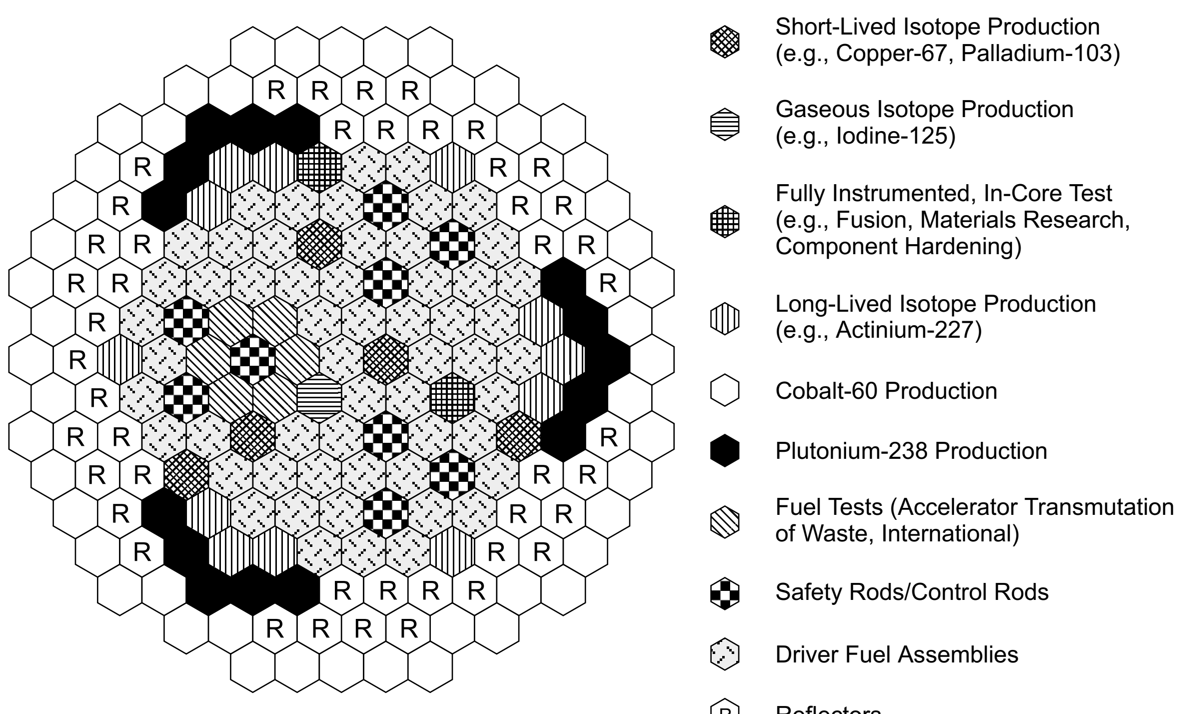
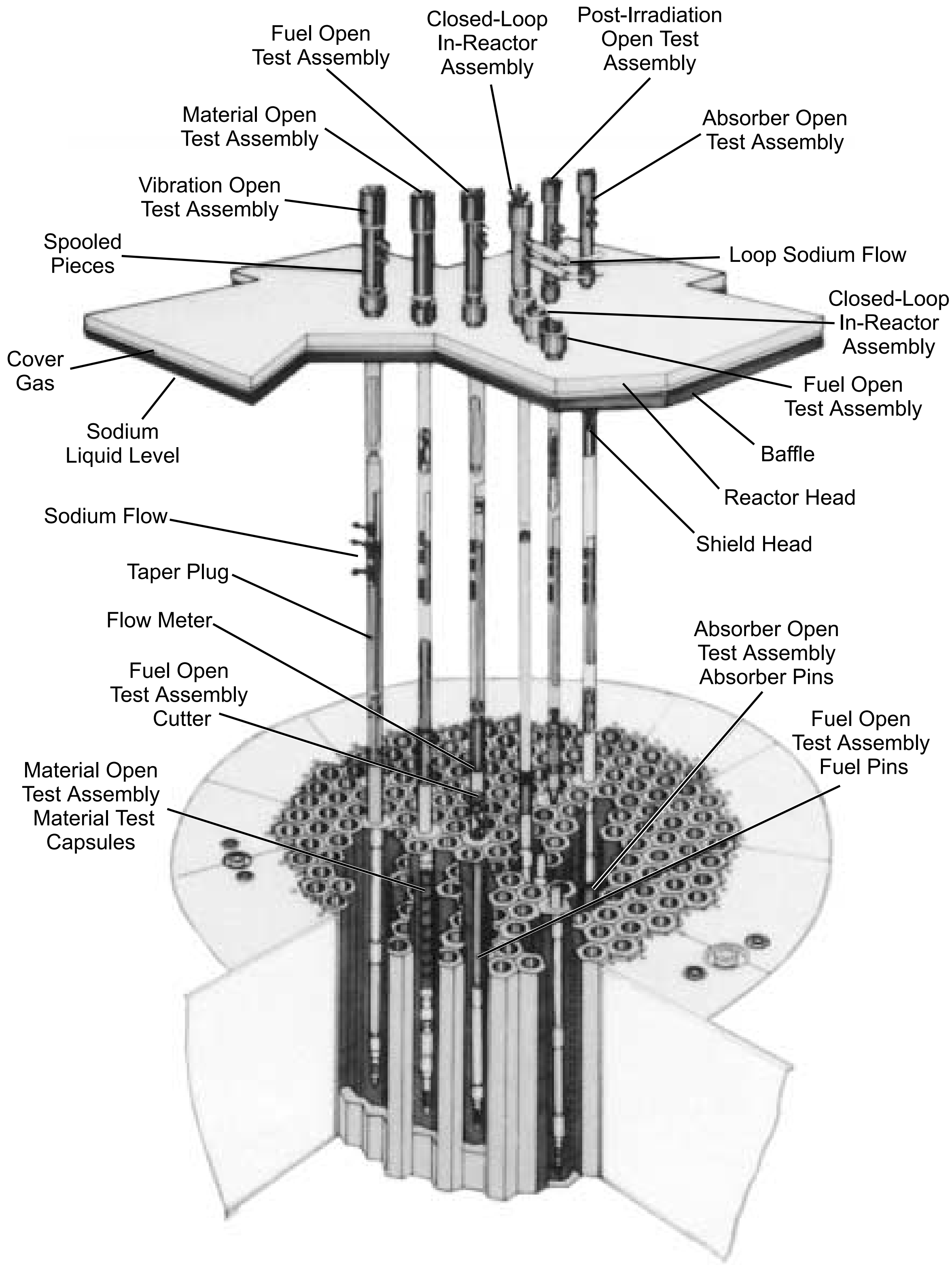


Figure D–3 Schematic View of One FFTF Cooling Loop



Source: Nielsen 1999.

Figure D–4 Multitest Core Example



Source: Nielsen 1999.

Figure D–5 Reactor Core with Various Test Packages Installed

Within the 82 active core locations, there are up to 20 or more additional locations that could contain a standard length (12-foot) irradiation assembly within the active core region. These locations also have specific on-line outlet temperature and flow measurements from installed plant instrumentation in the reactor core Instrument Trees, which are shown in **Figure D–6**. In addition to these test locations within the active fueled region of the core, there are 108 locations available in the surrounding reflector region where other irradiation assemblies could be inserted (e.g., plutonium-238 and cobalt-60 targets). These three basic irradiation configurations enable large-quantity and very diverse testing capabilities. Target designs vary according to the test requirements and the location of the test within the reactor.

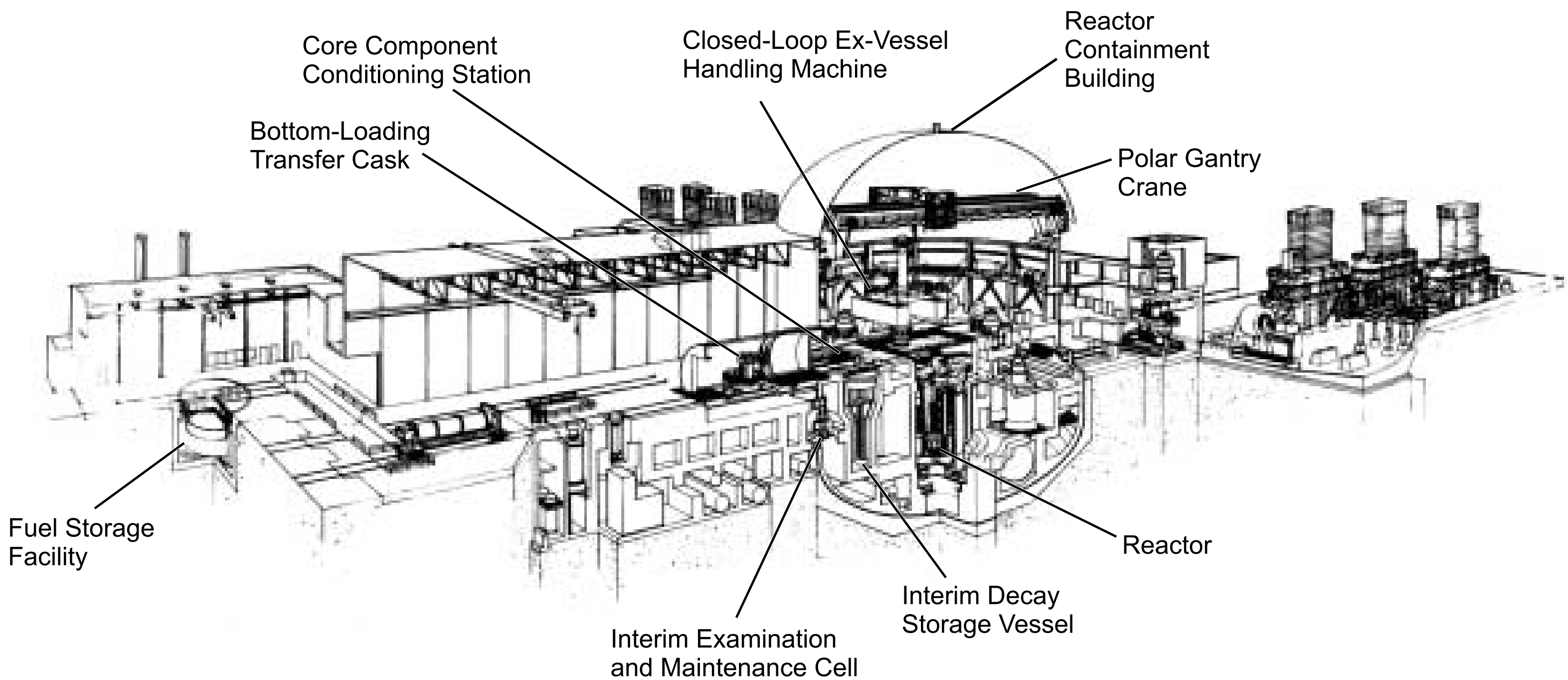
Source: Nielsen 1999.

Figure D–6 Instrument Trees Over the Initial (Unfueled) Core

D.2 LONG-TERM IRRADIATION VEHICLES

The Long-Term Irradiation Vehicles described in Appendix C (e.g., plutonium-238 targets and Long-Term Irradiation Vehicles for isotope production) would be installed in the reactor during normal refueling operations and would be handled using the standard FFTF component handling equipment. FFTF includes areas for receiving, conditioning, storing, installing, and removing from the reactor core all routinely removable core components. There are also areas for washing and storing irradiated fuel and nonfuel reactor components. Test and component examination and packaging capabilities also are provided.

FFTF uses state-of-the-art computer-controlled shielded transfer machines to perform reactor refueling operations as well as component and experiment transfers into and out of the reactor, the Interim Examination and Maintenance Cell, and into shipping/transfer casks. **Figure D–7** is a schematic of the equipment and transfer locations. The transfer machines are designed and operated with safety features and redundant systems to ensure safe transfer of irradiated materials. They are maintained reactor-grade clean; all internal surfaces are made of stainless steel and are maintained inert with argon gas.



Source: Nielsen 1999.

Figure D–7 FFTF Equipment and Transfer Locations

The Closed Loop Ex-Vessel Machine, **Figure D–8**, is used to handle both standard-length reactor components (i.e., 12 feet long) and longer test assemblies such as the open test assemblies described in Section D.3. The Closed Loop Ex-Vessel Machine is used for inserting all components into the reactor vessel. Open test assemblies are inserted directly into the reactor core and standard-length components are placed into In-Vessel Storage inside the reactor vessel before transfer into the reactor core. In-Vessel Storage modules are provided in three sections of the annular region between the core barrel and the reactor vessel thermal liner. Each storage module provides 19 natural-convection sodium-cooled receptacles for core components.

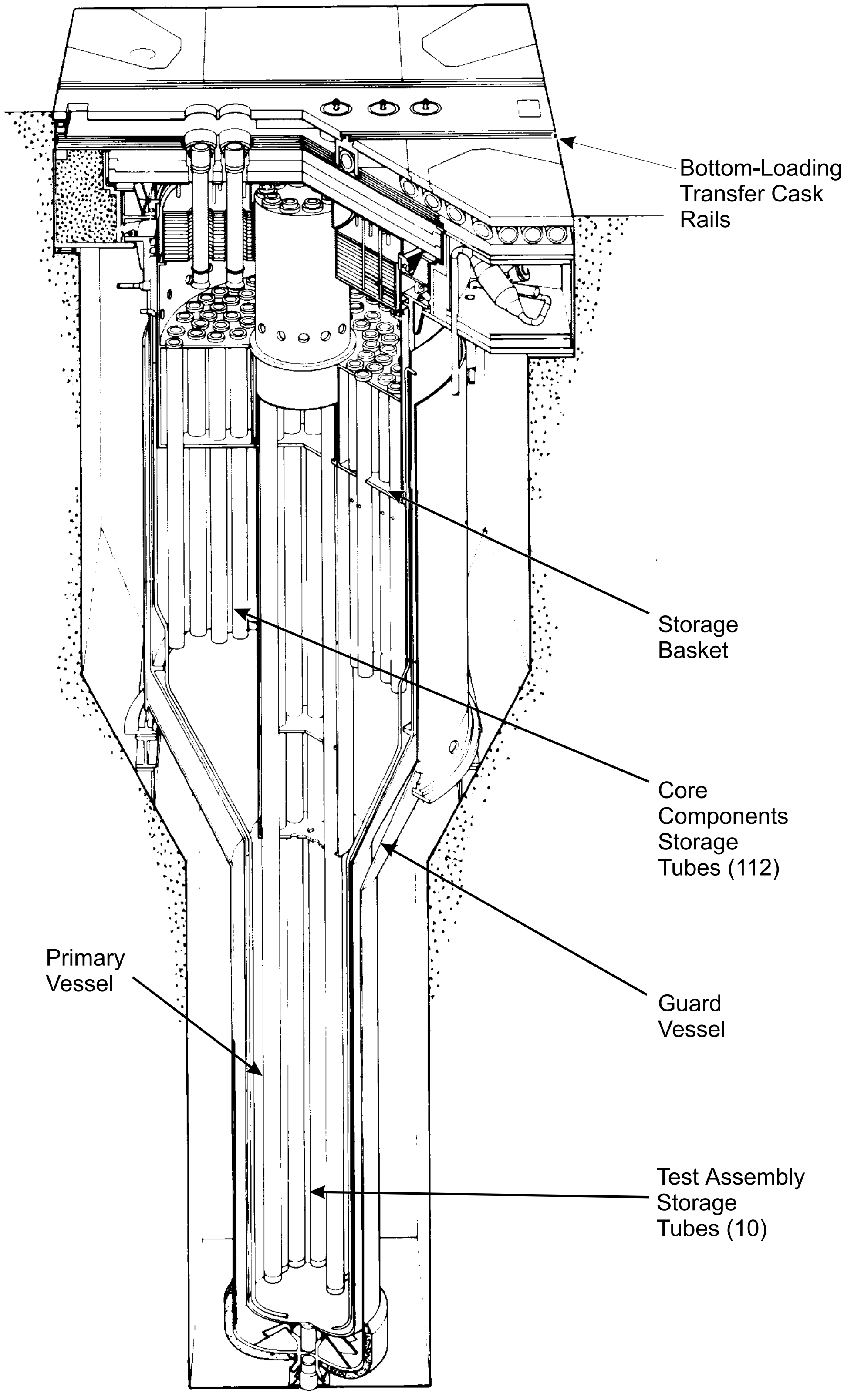
Source: Nielsen 1999.

Figure D–8 Closed Loop Ex-Vessel Machine

Assemblies for material surveillance samples can be installed in the In-Vessel Storage modules. During reactor operations, these samples are exposed to the sodium, thermal, and radiation environment typical of the reactor vessel.

The Closed Loop Ex-Vessel Machine is also used for the transfer of sodium-wetted irradiated components from the reactor vessel to either Interim Decay Storage (a sodium-cooled storage vessel inside containment shown in **Figure D–9**) or to the Interim Examination and Maintenance Cell, depending on whether it will be stored for later disposition or undergo examination. The standard-length assemblies are handled by one of the three In-Vessel Handling Machines for installation into or removal from the core. After irradiation, the Long-Term Irradiation Vehicles would be transferred to the Interim Examination and Maintenance Cell for washing and disassembly prior to shipment of the pins to the processing facility for isotope extraction and purification.

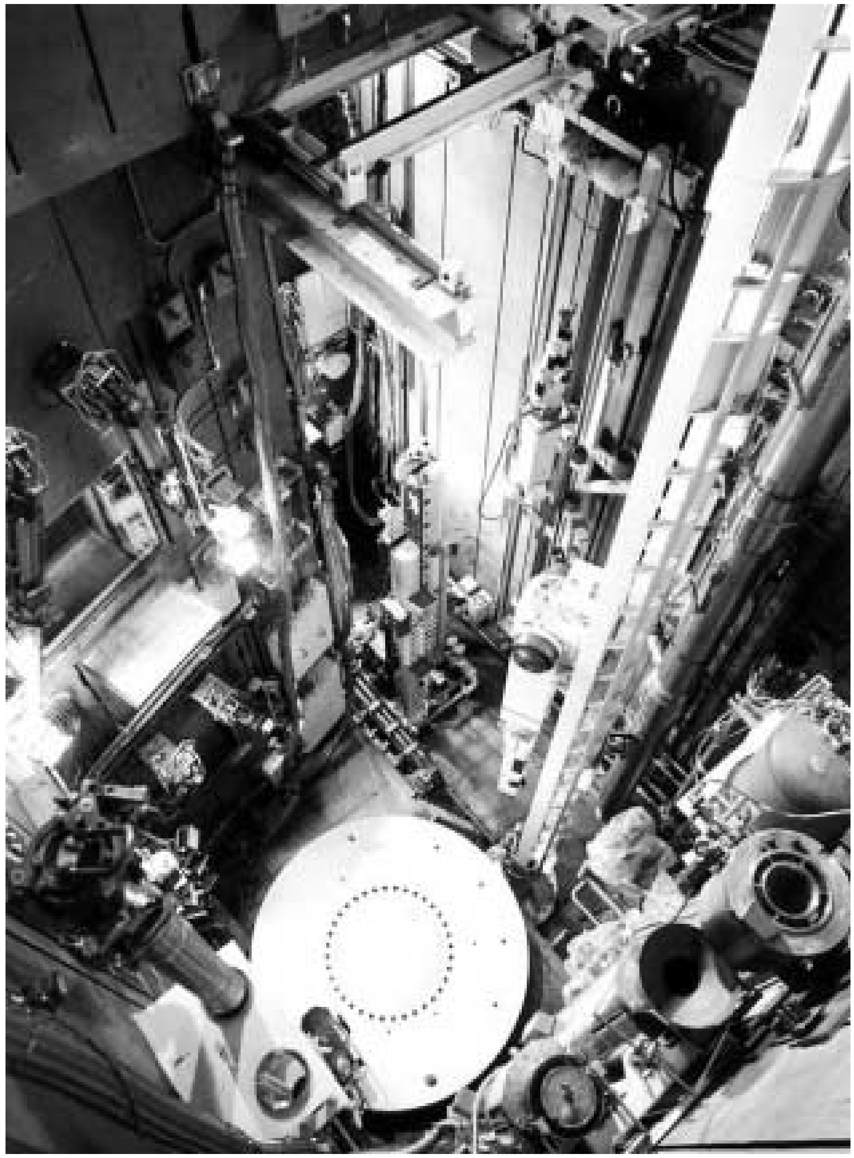
The Interim Examination and Maintenance Cell (**Figure D–10**) is a large, shielded, hot cell complex located inside containment that provides a reliable means of conducting nondestructive examination of test assemblies and core components under controlled argon- atmosphere conditions. Four levels of operating galleries provide visual access for remotely operating the in-cell equipment. This highly shielded hot cell has a



Source: Nielsen 1999.

Figure D–9 Interim Decay Storage Vessel

significant number of remote tools and equipment for diverse examination and disassembly needs. The hot cell, which is over 50 feet deep, contains two cranes and two very large electromechanical manipulators as well as multiple pairs of smaller master-slave-type manipulators at various operating levels for component and equipment handling. A sodium-cleaning station is available to wash irradiated components of all external sodium residues after removal from the reactor's sodium environment. This sodium-removal system has been used extensively to wash all fuel and experimental test assemblies processed in the Interim Examination and Maintenance Cell, as well as many of the FFTF spent fuel assemblies as they were offloaded to interim dry storage. The demineralized water used for washing is recycled through ion beds. The ion beds are periodically changed out and buried as low-level radioactive waste.



Source: Nielsen 1999.

Figure D–10 Interim Examination and Maintenance Cell

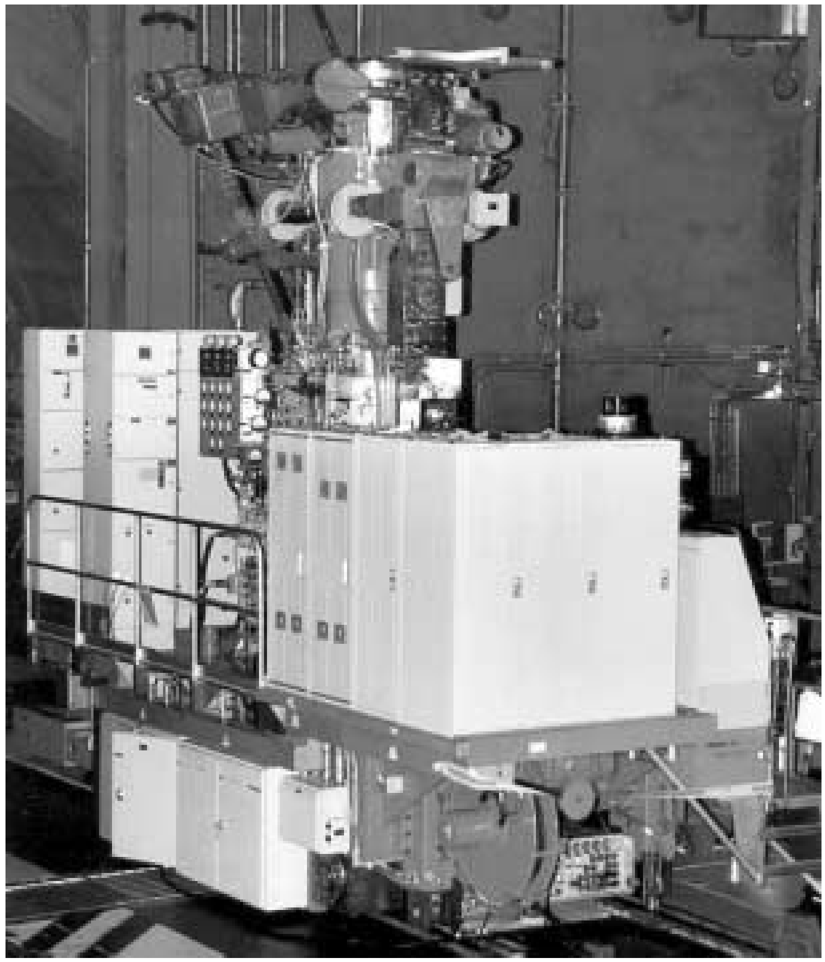
Following sodium removal and drying, irradiated components can be remotely disassembled using the manipulators, fixtures, and special tooling located within the Interim Examination and Maintenance Cell. For example, disassembly of plutonium-238 or cobalt-60 targets may be required to accommodate shipments of shorter target pin sections, depending on handling limitations of the selected processing facility. Various equipment is available for postirradiation examinations (e.g., weight, visual exam/photography, disassembly, and packaging for shipment). The hot cell also has been used for interim examination of tests and complex reassembly and qualification to allow a test to be returned to the reactor for further irradiation.

The Bottom-Loading Transfer Cask (**Figure D–11**) is used to transfer test articles, standard-length components, and specimen containers from the Interim Examination and Maintenance Cell to the cask loading station for transfer to offsite facilities for further examination, or to the Fuel Storage Facility (a sodium-cooled storage vessel located outside of containment) for subsequent storage.

Irradiation assemblies can be transferred from the Interim Examination and Maintenance Cell to the cask loading station for placement into shipping casks for transport to the processing facility or to offsite locations for testing, destructive examination, or other testing or processing. The cask loading facility has the capability to handle large spent fuel casks weighing up to 75 tons for vertical loading and unloading.

D.3 OPEN TEST ASSEMBLIES

During its 10 years of operation, FFTF supported a large and varied test program for industry, nuclear energy (domestic and international), nuclear defense, and medical research and treatment. The testing focused primarily on reactor fuel and different fuel assembly material evaluations, but also provided significant testing for many other programs. Following is a brief description of the major types of tests that were performed at FFTF using the open test assemblies. Similar test vehicles could be used to support the proposed new missions:

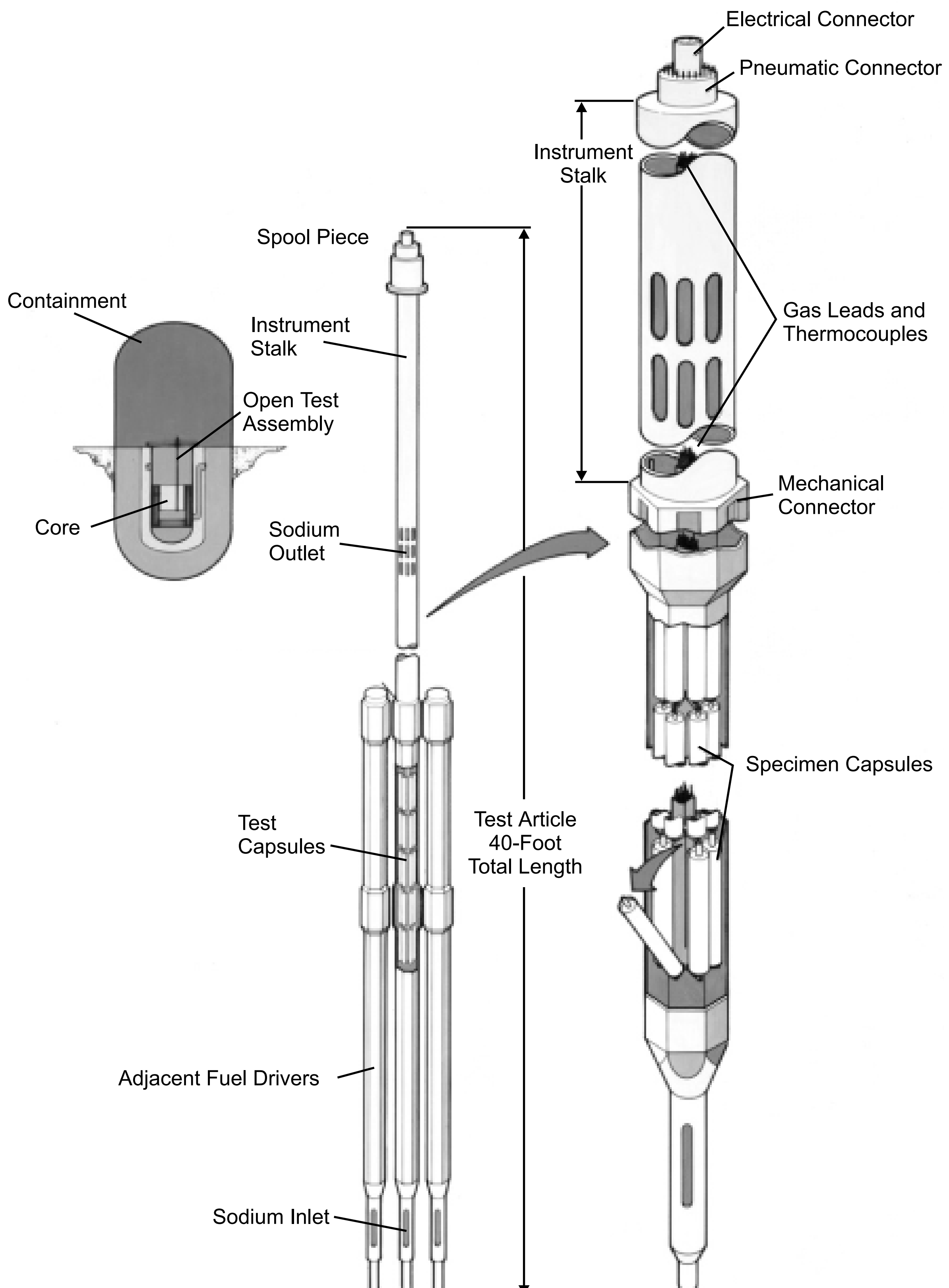


Source: Nielsen 1999.

Figure D–11 Bottom-Loading Transfer Cask

- **Material Open Test Assembly.** The 38-foot-long Material Open Test Assembly (**Figure D–12**) provided multiple containers capable of irradiating many different material specimens. Each container was individually temperature-controlled by the online mixing of argon and helium gases in the container annulus. This provided varying heat transfer from the container to the reactor sodium coolant. The support system for this test vehicle includes multiple gas lines, temperature control loops, and an online control and monitoring system.

- **Fusion Material Open Test Assembly.** The reactor portion of this test vehicle was essentially identical to the Material Open Test Assembly and included many material test specimens as well as the two canisters that were part of the fusion testing program. This test series was a joint venture for the United States, Canada, and Japan to evaluate tritium production by the irradiation of lithium oxide. The purpose of the experiment was to measure tritium release characteristics and thermal stability of lithium oxide as a function of neutron exposure, temperature, gas composition, and sweep gas flow rates. This equipment also included the instrumentation and controls for tritium measurement, analysis, and recovery.



Source: Nielsen 1999.

Figure D–12 Material Open Test Assembly

- **Absorber Open Test Assembly.** The Absorber Open Test Assembly provided for online instrumentation (temperature and pressure) of standard boron carbide absorber pins used in reactor control and safety rods.

- **Fuel Open Test Assembly.** The Fuel Open Test Assembly provided direct measurement during reactor operation of temperatures and pressures of individual fuel pins allowing monitoring of fuel assembly performance during the entire irradiation phase.

D.4 Rapid Radioisotope Retrieval Systems

Rapid retrieval systems would be installed in selected open irradiation assembly positions for the production of short-lived isotopes. These systems would allow target materials to be inserted and withdrawn from the reactor core region with the reactor operating at power. Systems for routinely inserting and removing irradiation targets, nuclear instrumentation, and research hardware at an operating reactor have been in use at various research reactors throughout the world for years. Most of these systems use either a pneumatic rabbit-type system or a mechanical cable-type system for insertion and retrieval. **Figure D–13** is a conceptual layout of an FFTF rapid retrieval system, which consists of three major components: a 40-foot-long in-reactor thimble assembly, a replaceable string or chain of isotope target carriers, and a target carrier insertion and retrieval system.

The target carrier insertion and retrieval system(s) would be installed external to the reactor to shuttle a target carrier chain into and out of the core region. This system could use some form of mechanical cable insertion and retrieval mechanism or could be based on a pneumatically operated system. Ideally, the insertion and retrieval system would load irradiated target chains directly into the transportation cask for shipment to the hot cell laboratory facilities for isotope separation and purification.

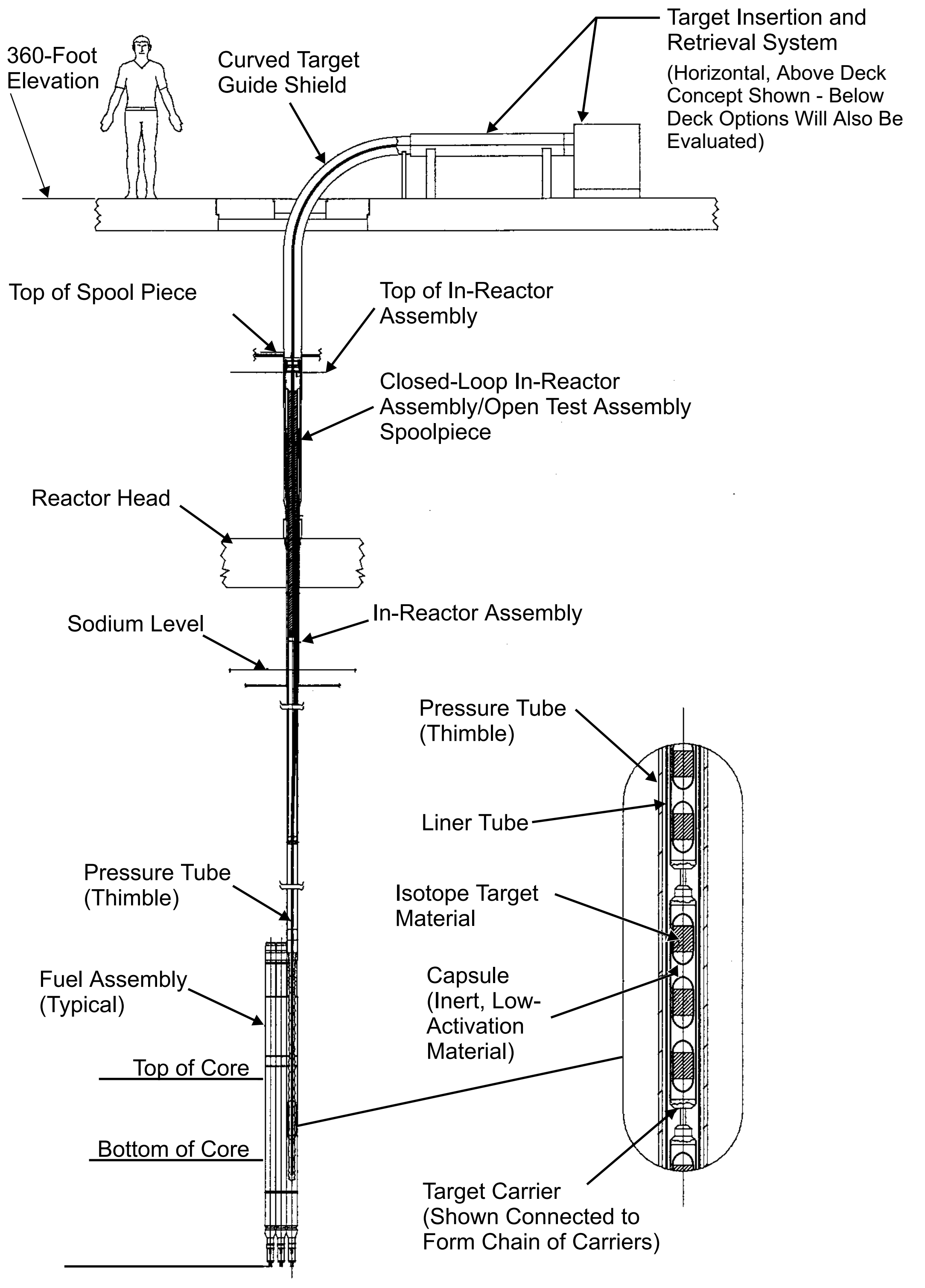
In addition to irradiating solid targets in the rapid retrieval system carrier chains, gas targets also could be irradiated to produce short-lived isotopes. Two options would be evaluated for producing the gas-based isotopes. One option would involve one or more small-diameter, thin-wall tubes routed down through the in-reactor thimble assembly into the active core region. These tubes would be connected via shielded and preheated tubes to a shielded ex-reactor gaseous isotope recovery system. The practice of routing external gas lines into the active core region is not new at FFTF and has been used in several irradiation test assembly designs installed in the reactor (e.g., the Material Open Test Assembly used externally supplied gas mixtures to control material sample temperatures, and the Fusion Material Open Test Assembly had gas lines routed to a glovebox for tritium sampling and gas analysis).

A second option for producing gas-based isotopes would involve irradiating capsules filled with a high-pressure target gas. The gas-filled capsules would be installed in a target carrier and could become part of a target chain.

D.5 Reactor Core Configuration Planning

Typical operating cycles for FFTF were approximately 100 days at power followed by shutdown periods that ranged from approximately 20 to 30 days for short outages to 60 to 90 days for extended outages, depending on the extent of maintenance and refueling to be performed. These same operating cycles were assumed for evaluating restart activities. There may be benefits to longer operating cycles (e.g., increased capacity factor, reduced equipment use); therefore, future consideration may be given to such intervals.

Reactor core configuration planning would be completed prior to the start of reactor servicing in preparation for the next operating cycle. This planning would accommodate the user-defined irradiation requirements for



Source: Nielsen 1999.

Figure D–13 Conceptual Layout of the Rapid Radioisotope Retrieval System

each target. Those requirements typically would be defined in terms of neutron energy and flux level, duration of the irradiation (or cumulative exposure), and temperature. Given these requirements, the in-core location for each target assembly would be analyzed and decided based on the neutron energy and flux level at that location; the neutronic characteristics of adjacent assemblies; coolant flow and temperature at that location; reactor power level; target gamma heating and the resultant target temperature; and planned operating cycle duration. The resultant core configuration would have to meet the nuclear safety requirements and limitations defined in the Final Safety Analysis Report and the Technical Specifications.

During prior FFTF operations, the reactor physics and nuclear safety aspects of the planned core configuration were analyzed prior to the start of each operating cycle. If FFTF is directed to restart, the reactor initially would be refueled similar to the configuration in place at shutdown. The data from that operating cycle would be included in analysis of the reloaded core to predict safety margins and control rod positions for initial criticality. Following completion of physics testing of that initial core configuration, it would be used as the "reference core configuration," from which each subsequent core configuration change made to accommodate fuel burnup and irradiation service requirements would be analyzed for control and safety purposes.

D.6 TARGET TEST AND DEVELOPMENT

Testing programs would be conducted for new materials and target designs to be irradiated in the reactor. Brief descriptions of the types of testing that would be associated with the plutonium-238 and medical isotope production missions are given below.

Plutonium-238 Production—As discussed previously, it is expected that the targets used for plutonium-238 production in FFTF would be similar to the concepts developed during the plutonium-238 production core study that was done between 1992 and 1993. Target design would be based on alternating thin pellets or wafers of neptunium dioxide and yttrium hydride. To support the final design of the initial plutonium-238 production target assemblies, at least one lead test assembly would be designed and fabricated to be available after the initial low-power physics testing. Confirmatory irradiation tests would be done in the lead test assembly(ies) at the core periphery prior to the start of fabrication of the plutonium-238 production assemblies. These tests, which would require small amounts of neptunium dioxide, would be done to demonstrate items such as target wafer integrity and dimensional stability, and to confirm target isotopic content from irradiation. Additionally, exploratory materials tests would be irradiated in parallel to investigate any material compatibility or performance issues, and to evaluate options to improve plutonium-238 production rates or optimize/reduce target fabrication costs. These tests, which could be done under accelerated irradiation conditions in a variety of assemblies such as the Long-Term Irradiation Vehicle, could include tests of other hydride materials such as zirconium hydride or calcium hydride as well as various foil wrapper and cladding materials.

Medical and Industrial Isotope Production—A testing program would be performed to support the development and detailed design of the Rapid Radioisotope Retrieval system and the associated initial targets. Feature tests would be conducted as necessary to support development of key portions of target insertion, retrieval, and handling equipment. High-temperature furnace tests would be performed as required to ensure materials compatibility for those materials or material combinations for which high-temperature data do not exist. This would be done both for the Rapid Radioisotope Retrieval system and for the Long-Term Irradiation Vehicle assemblies. A full-scale, heated mockup of the key portions of the Rapid Radioisotope Retrieval system would be built, and insertion and retrieval tests performed using simulated targets and target strings. Ex-reactor modifications needed to support insertion, production, and retrieval of targets in Rapid Radioisotope Retrieval assemblies would be completed, and acceptance tests conducted to the extent possible before initial criticality on restart.

Following initial criticality and low-power physics testing, the reactor would be shut down and the lead Long-Term Irradiation Vehicle assemblies and at least one 38-foot-long Rapid Radioisotope Retrieval assembly inserted in the reactor. Following additional acceptance testing and low-power physics testing, including Rapid Radioisotope Retrieval characterization, the lead targets would be installed in the Rapid Radioisotope Retrieval assembly. These could consist of relatively small quantities of key target materials plus dosimeter sets for neutron environment characterization. On removal from the reactor, the initial targets irradiated in the Rapid Radioisotope Retrieval assembly would undergo a variety of special inspections, tests, and radioassays as part of a characterization and target qualification program. Over a period of months, the quantity of target material incorporated into the Rapid Radioisotope Retrieval targets would be increased as feasible to provide beneficial quantities of product isotopes. As the demand for short-lived isotopes grows, additional Rapid Radioisotope Retrieval assemblies and associated support systems would be installed in the reactor as needed to support production.

D.7 Nuclear Research and Development

FFTF has demonstrated the capability to produce high-energy, high-fluence neutrons for multiple nuclear science and irradiation services applications. High-energy neutrons are fast neutrons that can be used for the transmutation of elements into useful isotopes (e.g., medical and industrial) and for the investigation and development of materials and components that can be used in harsh, radioactive environments (e.g., fusion reactors). High fluence refers to FFTF's capability to produce a lot of neutrons in a given test volume within the reactor.

The large test volume in FFTF allows the production of larger quantities of isotopes and the ability to test more materials and components when compared to other neutron sources. While other neutron sources may have similar neutron high energies or fluences, FFTF is unique in simultaneously providing all three attributes in a single test facility. FFTF can also produce large quantities of epithermal neutrons by the use of moderating materials that slow down the neutrons in specific areas of the core. These distinctive flux tailoring features, coupled with its large core volume, the ability to vary power from a nominal 100 megawatts up to 400 megawatts, and highly instrumented testing capabilities, enable the reactor to function successfully as a multiple-mission nuclear science and irradiation services facility. Researchers from many different countries have used FFTF for nuclear materials testing and fuel research.

There is particular interest in materials testing associated with extension of commercial nuclear power plant license renewals, cooperative international fusion energy research, space power technology, and transmutation of wastes as a means to destroy long-lived isotopes from commercial spent nuclear fuel. Another area of interest is developing nuclear technologies that advance global nonproliferation. FFTF is ideally suited for the study, research, testing, development, and demonstration of technologies necessary to safely convert plutonium-based materials for disposition and use as proliferation-resistant fuel. Target assemblies to be irradiated in support of these mission areas could be fuel or other materials configured similar to a standard driver fuel assembly (i.e., target material encased in sealed pins and the pins placed in a ducted assembly). Material specimens could also be installed in an open test assembly position within a Material Open Test Assembly, which is described in more detail in Section D.3.

One of the proposed testing activities consists of fuel testing for the Accelerator Transmutation of Waste program. A fuel development activity for this program could use FFTF for irradiation testing. The tests would be fabricated by the Accelerator Transmutation of Waste program and transported to FFTF for irradiation. Specific test compositions and irradiation parameters for these test fuel assemblies have not been defined. It is anticipated that initial tests would involve a few pins in an assembly, while later tests could involve entire assemblies. The target pins are described as containing a matrix of zirconium and transuranic elements; a composition of 75 percent zirconium and 25 percent transuranic elements, by weight. The transuranic elements would likely be light water reactor discharge fuel at a typical burnup of 33,000 megawatt-days per metric tons of uranium that is stripped of essentially all uranium and fission products. Comparisons of this fuel to the standard FFTF fuel indicate comparable plutonium compositions. Therefore, for purposes of this environmental impact statement evaluation, the Accelerator Transmutation of Waste fuel assemblies were modeled as standard FFTF driver fuel assemblies.

D.8 REFERENCES

Nielsen, D.L., 1999, *Fast Flux Test Facility Data Request in Response to Data Call for Nuclear Infrastructure Programmatic Environmental Impact Statement*, BWHC-9958233, B & W Hanford Company, Richland, WA, December 21.